WORK STATEMENT

TITLE

Relate air quality and other factors to comfort and health related symptoms reported by passengers and crew on commercial transport aircraft.

BACKGROUND

Symptoms such as eye irritation, headache, fatigue, dizziness, and nausea are reported on occasion by passengers and crew flying on commercial aircraft. These symptoms have often been attributed to poor cabin air quality. Several scientific investigations conducted by government agencies, independent research groups and airplane manufacturers have not been able to show elevated concentrations of contaminants or correlations between cabin air quality and the reported symptoms. However, contaminants potentially generated by the airplane bleed air system, such as volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), have not been measured on a sufficient number of flights to draw firm conclusions. In addition, the impact on air quality of aircraft age, maintenance practices and design/configuration changes after the airplane is manufactured is not well understood.

One of the first studies that explored the relationships between measured air quality data and perceived symptoms on aircraft was ASHRAE research project 957-RP. The first bleed air contaminant research study was ASHRAE research project 959-RP. These two ASHRAE research projects were aimed at developing methodologies necessary for a comprehensive study of the effects of air quality and other factors on passenger and flight attendant comfort and health-related symptoms. This research project is the comprehensive study envisioned by the TC 9.3 Aviation Research subcommittee, utilizing ASHRAE research projects 957-RP and 959-RP as its foundation. This project will also evaluate effects of factors, such as aircraft types, maintenance, engine age and type, as well as length of flights, on bleed and cabin air quality.

The greater understanding of the causes and effects of all factors experienced in the airplane interior will be useful to ASHRAE and European Cabinair in supporting the development of air quality standards for commercial aircraft. The information on cabin environment factors will be useful to airframe manufacturers in future design for improving passenger and crew comfort. Furthermore, information on symptoms and their potential causes can be used by the medical community in educating their patients about the unique cabin environment.

JUSTIFICATION OF NEED

This research is needed to support the development of ASHRAE standard SPC 161P for air quality in transport category commercial aircraft in order to ensure that cabin air: 1) is safe for flight crew and occupants; 2) minimizes the potential for adverse health effects; and 3) is comfortable to occupants (consistent with high-altitude travel). The airplane cabin environment presents a unique environment compared to other environments that most people will experience: the cabin pressure can be reduced to 8,000 feet above sea level, thus lowering the partial pressure of oxygen in the air; the humidity level drops to between 5 to 20%; the plane can fly across time zones, affecting a person's circadian rhythm; there is continuous three-dimensional motion, noise and long periods of inactivity. There are also variations in health status as well as factors such as alcohol consumption among passengers resulting in people being affected to different degrees by air travel. There are additional impacts on flight attendants due to the nature of their work, such as highly variable work schedules and schedules that include multiple short-haul flights per day or long-haul flights across multiple time zones.

Standard developers need data to support decisions regarding the components and contaminants of air that are responsible for symptoms in humans, and to distinguish such effects from effects of such factors as age, cabin altitude, humidity, inactivity, duty schedules, stress and fatigue. A literature search of possible causal factors is necessary to develop a current understanding of symptoms caused by cabin air quality and to differentiate them from those caused by other factors. Understanding of the contribution to cabin/bleed air quality from factors related to maintenance and engine age is necessary for better design and operation of the aircraft ECS systems. Similarly, the impact of ground air quality on cabin air quality needs to be understood.

A common technique used for building air quality investigations is to correlate perceived symptoms with measured air quality constituents. This technique has only begun to be used on airplanes and standardized protocols to address such

objectives are not available. The European Cabinair research effort, utilizing questionnaires, will allow collection of such data. Some level of research coordination with that project will benefit this ASHRAE research project. However, there are some significant differences in the research designs. ASHRAE research will have an increased emphasis on bleed air contaminant measurements and will hand out questionnaires to passengers and flight attendants. Cabinair research is limited to questionnaires for flight attendants only and has a limited bleed air quality component.

The results of this research project will provide an improved basis for developing cabin air quality standards. Results will also be of direct use to aircraft manufacturers in improving design and will provide the needed information for airlines regarding operating and maintenance practices. It will also serve to educate professionals from a variety of fields including engineers, physicians, operating personnel, aircraft crew and passengers in the U.S. and abroad. The study will also provide an improved basis for future legislative and regulatory actions.

OBJECTIVES

The principal aim of this research project is to relate perceptions of discomfort or health related symptoms of flight attendants and passengers to possible causal factors, including cabin and bleed air quality and other factors such as reduced air pressure, jet lag, inactivity, humidity, flight attendant duty schedule and fatigue, circadian rhythm, stress and noise. In particular, the following specific objectives are to be addressed in this project:

1. Conduct a literature review of chemical and other factors associated with airplanes and flying that are known to cause symptoms in passengers or flight crew, such as eye, nose, throat and skin irritation, headache, dizziness/fainting, nausea, ~~and~~ respiratory stress, irritancy and neurological symptoms.
2. Measure and characterize contaminants in cabin air that are caused by engine bleed air in a variety of airplane types.
3. Measure and characterize contaminants in cabin air that are not related to engine bleed air.
4. Quantify the effect of aircraft type, maintenance, engine age and operations-related parameters on cabin and bleed air quality
5. Statistically relate the measured cabin air contaminants and other factors with reported symptoms among passengers and flight crew.

It should be noted that objective 1, the literature review, is in support of all remaining objectives. Objectives 2 through 5 will receive primary emphasis.

Data will be collected on a sample of flights recording cabin and bleed air quality and other parameters. In parallel, perceptions of flight attendants and passengers will be recorded using questionnaires. The design of the study is to consider a variety of objective parameters such as aircraft type, air quality, cabin altitude, passenger load, length of flight, and thermal environment. The subjective parameters to be considered include passenger and flight attendant comfort during flight, health status at the beginning and during flights, and indicators of susceptibility. The design must consider the testing protocols and methodology developed for ASHRAE 957-RP and 959-RP. The design should evaluate other relevant past and ongoing research with the aim of developing standardized methodologies.

SCOPE

The proposed research includes two major parts. A contractor for Part 1 will be selected first. Upon completion of Part 1, proposals will be solicited for selecting a contractor for Part 2.

Part 1. Literature Review, Protocol Development and Pilot Test

I. Literature Search on Contaminants and Other Factors

The contractor will perform a literature search to identify possible causal factors present in the air in aircraft cabins as well as factors present in aircraft but not related to air quality. The following should be included as sources for the literature search and review:

a. National Research Council Report: "The airliner cabin environment and the health of passengers and crew"(2002).
~~a.~~b. Peer-reviewed literature, including but not limited to scientific and technical journals;
~~b.~~c. FAA Aviation Medical reports, Aerospace Medical Association reports, and reports from other relevant government organizations or professional associations;
~~c.~~d. Flight attendant studies conducted by airlines, flight attendant unions and independent researchers;

~~d.~~ c. Research reports published or issued by different organizations; and
~~e.~~ f. The literature search and bibliography listing developed for ASHRAE 957-RP.

A partial list of relevant references is also included at the end of this work statement.

The contractor will review contaminants present in the cabin and bleed air, develop a list of such contaminants, and review associated guidelines such as NAAQS and other public and occupational health standards and guidelines. The contractor will review and assess the impact of cabin environment factors such as cabin air quality, altitude, low humidity, turbulence, three-dimensional motion, seat comfort, continuous noise, vibration, cabin temperature, air velocity, and odors on comfort and acute health effects of passengers and flight attendants. In addition, factors impacting passengers such as health status, age, anxiety, stress, and work demands immediately prior to and following the flight should be included in the review. The flight attendant work-related factors to be considered include duty schedule, sleep disruption, work-schedule variability, multiple short-haul flights, long-haul flights across time zones, and other related factors. The review of the cabin environment, passenger, and flight attendant work related factors will primarily be from a perspective of considering relevant factors in the design of the study. This review should also be used in developing appropriate questions for the flight attendant and passenger questionnaires. The contractor will identify characteristics of high-risk group individuals, who may be at an increased health risk due to their pre-flight condition and exposure to the above cabin environment factors.

Although a broad based literature review is necessary for this project, the contractor shall ensure that the extent of the effort for literature review does not exceed about 20% of the phase I project effort.

II. Measurement Protocol, Pilot Testing, and Standardization

Following the completion of literature review, the principal investigator shall provide to the Project Monitoring Committee (PMC) an overall design of the study. A primary component of the overall design will be a well-thought through experimental design (design of experiment) of the study. Such experimental design for the study will evaluate different approaches for obtaining data that provide a maximum clarity and a degree of statistical validity in meeting the project objectives. Because of practical limitations on sample size, it is recognized that simple randomized design may not provide a sufficient basis for meeting the objectives. Further, the design would consider how certain variables could be controlled so that other variables of interest can be examined in more detail. ~~, including~~

The overall design will also include methodology for selection of the flights and/or aircraft, identification of contaminants generated by aircraft equipment and operations and other factors to be monitored, and a general approach for the study including the type of questionnaire data to be collected. Upon review of the design by the PMC, the principal investigator shall provide the PMC a detailed protocol for air quality monitoring including details on test equipment package, questionnaires for passengers and flight attendants and logistics. A quality assurance plan will be a part of this protocol. The test protocol should also include equipment correction factors due to the reduced air pressure. The PMC will review and approve this protocol package prior to the start of testing. The principal investigator may be directed to make adjustments to the above submissions.

Monitoring of air quality parameters will be conducted with passengers on board when the airplane is on the ground and during cruise. If allowed by airlines, monitoring may be conducted before passengers board, since the cabin and flight crew may be exposed to possible fumes from cleaning and maintenance – and such monitoring may also provide a useful background value prior to boarding by passengers. Measurements of bleed and cabin air quality will include: carbon dioxide, carbon monoxide, individual volatile and semivolatile organic compounds, ozone, cabin pressure, humidity, and respirable suspended particulate levels. In addition to carbon dioxide, levels of bioeffluents such as ethanol and acetone shall be quantified. Measurements of partial pressure of oxygen and air temperature in the cabin will be included. In parallel, an attempt should be made to measure blood oxygen saturation of cabin crew. Measurements of temperature and air velocity should include some multi-point measurements, especially on long-duration flights, to indicate temperature and velocity profile in the cabin. Measurements of turbulence, 3-D motion, noise, lighting, ventilation effectiveness, and other such factors as well as concentrations of biological agents (aeroallergens and toxins) in the cabin air and settled dust should be considered. Previous ASHRAE cabin/bleed air quality and the EU Cabinair studies should be reviewed. Ventilation rates shall be determined by utilizing carbon dioxide measurements. Equilibrium carbon dioxide levels should be reached within 10 minutes of steady state conditions. ASTM D6399 *Standard Guide for Selecting Instruments and Methods for Measuring Air Quality in Aircraft Cabins* should be used as a basis for the selection of equipment and methods to be used in this research.

In-flight data must be obtained with the same equipment as the ground-based data with adequate calibration and

certification. Provision must be made for the equipment to be calibrated for the monitoring environment – both at ground level and at high altitude.

To the extent feasible, air quality monitoring should be performed innocuously so as not to influence occupant answers to the questionnaire. In the past, in-flight comfort questionnaires have been developed which are designed to specifically look at cabin air quality and other factors which can affect passenger and crew comfort and health related symptoms. ASHRAE research project 957-RP and EU Cabinair have developed questionnaires specifically for use on airplanes. Comfort questionnaires have also been developed for use in buildings. It is recommended that existing questionnaires designed for use on airplanes be used as an initial outline for questionnaires to be developed for this project. Recently developed airplane questionnaires can be obtained through the ASHRAE TC 9.3 Aviation Research subcommittee. The chair of the subcommittee is Karin Arnold, phone (905) 608-6000 ext. 2804, who will coordinate review and acceptability of the questionnaires with participating airlines.

ASHRAE Research has solicited help from airlines and others to support this research effort. Contacts are available from the TC 9.3 Aviation Research subcommittee chair. Working with the selected contractor, it will be the responsibility of the PMC ~~Chair [name to be added]~~ to persuade and enroll the airlines and to obtain the needed flexibility to select aircraft and flights and to conduct monitoring. The contractor's responsibility will be to continue to work out study procedures with the enrolled airlines and to gain their cooperation for conducting the study. Authorization to conduct research will be coordinated, as necessary, by the TC 9.3 Transportation Committee chair and the PMC chair with the Federal Aviation Administration and participating airlines. The chair of TC 9.3 is David Space, phone 425-294-3166.

The contractor will obtain EMI certification for carrying equipment on revenue aircraft. The contractor will work with the selected airlines and FAA representatives to obtain permission to carry scientific equipment on the flight, including batteries, laboratory supplies, and small tools. The Research Committee or Transportation Committee chair will facilitate obtaining such approvals. The contractor will also work out with the designated airline representatives all logistical details, including procedures for the administration of questionnaires to passengers and flight attendants, obtaining in-flight data from the cockpit crew, and the installation of equipment in the cabin.

The contractor must provide to the PMC the overall design and detailed draft protocol for review and approval. Concurrently, the protocol should be submitted to ASTM committee D22 for initial review of the measurement methodology. Care should be taken to elicit comments from the ASTM committee without causing a delay (i.e., over 6 weeks) to the project. In all cases, the PMC will have the final say in approving the design and protocol. Following the approval of such a protocol, the contractor will test the protocol on four to six flights. These flights should be at least three hours in duration. A minimum of two different types of aircraft will be included in the pilot test. Consistent with the approved protocol, the pilot testing should include comprehensive data collection for all selected factors and parameters.

During monitoring, the contractor must note whether the airplane has recirculation filters and ozone converters, and record relevant part numbers and service and operational information for both. Contractor will seek data on engine oil and hydraulic fluid consumption from airline. In addition, the airplane engines and auxiliary power unit total operating hours shall be recorded along with the time since last maintenance. The PMC ~~chair~~ will facilitate procedures for gathering this information from participating airlines. The contractor must also note pack operation, the airplane configuration and items that could affect cabin air quality, e.g., air conditioning packs turned off for a no pack take-off or a recirculation fan turned off. This information will need to be obtained directly from the airplane flight crew.

At the conclusion of the pilot test, the contractor will prepare a report for Part 1 that will address: (1) comprehensiveness and appropriateness of the protocol in light of the project objectives; (2) details on selection of flights; (3) detailed procedures, including calibration procedures, used in collection of the data and recommended improvements; (4) the quality of questionnaire responses, response rates and recommendations on improvements; (5) list of parameters to be included in the Part 2 study; (6) adaptation of the procedures developed for aircraft included in the pilot study to other types of aircraft; and (7) comments and recommendations on logistical and related matters to streamline the data collection process. The report will also include a detailed protocol for Part 2. The draft Part 1 report will be submitted to PMC for review and approval.

Following the revision and approval of the Part 1 report by the PMC, the contractor shall initiate the process of standardization of the protocol through the ASTM committee. During the consensus development process, the contractor should provide practical insights into the methodology based on the field experience. The PMC must be tied in directly with the research and standardization, being kept up to date with all major activities and receiving copies of all correspondence.

Part 2. Sample Selection, Monitoring, Analysis, and Final Report

III. On-Ground and In-Fight Monitoring

The protocol and procedures developed in Part 1 shall be the basis for conducting on-ground and in-flight monitoring under Part 2. Based on Part 1 protocol, a monitoring and quality assurance plan shall be developed for Part 2 by the contractor selected for Part 2 for review by the PMC. The standardization activities initiated in Part 1 will be continued by the Part 2 contractor.

Air quality monitoring shall be conducted on different models of commercial jet airplanes representing a large section of the world fleet. The airplanes shall be selected from three different airlines and include a minimum of xxx[1] flights total. Flight selection shall consider aircraft type, operating hours on engines, and flight routes to provide a representative cross-section of airplane types and routes flown. Additional factors to be considered in selecting flights include:

- Type of air conditioning systems (ECS) and APUs;
- Type and quality of ground service air supplied to the aircraft (portable, remote, none, filter air/unfiltered) (whether customization was performed after initial delivery from manufacturer);
- Type of fueling and service equipment used;
- Cleaning procedures, both inside and outside;
- Age of aircraft; and
- Age of service equipment.

Research will be performed using a variety of aircraft taking off from multiple airports and revenue flights in a variety of operating modes. The flights shall include domestic and international flights. It is recognized, however, that one of the main criteria for the selection of carriers will be their readiness to agree to in-flight monitoring as well as to administering questionnaires to their passengers and/or crew. For this purpose a waiver will be prepared that can be signed by the participating airline, waiving potential liabilities through research findings and clarification of ASHRAE's fundamental principles that include anonymity.

Measurements of bleed and cabin air quality are to include: carbon dioxide, carbon monoxide, volatile and semivolatile organic compounds, ozone, cabin pressure, humidity, and respirable suspended particulate levels. Measurements of partial pressure of oxygen and air temperature in the cabin will be included. Measurements of temperature and air velocity should include some multi-point measurements, especially on long-duration flights, to indicate temperature and velocity profiles in the cabin. Measurements of turbulence, 3-D motion, noise, lighting, ventilation effectiveness, and other such factors should be considered, at least on a fraction of the total flights. Also, on a limited number of flights biological agents, such as aeroallergens and endotoxins, in the cabin air and in settled dust will be measured.

As stated earlier, ASHRAE Research has solicited help from airlines and others to support this research effort. Contacts are available from the TC 9.3 Aviation Research subcommittee chair. Working with the selected contractor, it will be the responsibility of the PMC chair to persuade and enroll the airlines and to obtain the needed flexibility to select aircraft and flights and to conduct monitoring. The contractor's responsibility will be to continue to work out study procedures with the enrolled airlines and to gain their cooperation for conducting the study.

IV. Analysis of Results and Final Report

1. Assess the quality of data collected and demonstrate adherence to quality assurance plan.

2.Generate and assess a list of contaminants based on this and previous research and identify potential sources of such contaminants. Health guidelines and standards, such as NAAQS, and SMACs, will be compiled for these contaminants by reviewing and assessing appropriate databases. In addition, contaminants with a high frequency of occurrence and concentration but not reflected in the above-mentioned documents would be investigated for generation of irritation, odors or other reactions.

[1] The minimum number of flights to be included will depend on the availability of research funds and will be specified in the solicitation for Part 2 to be released by ASHRAE in the future.

2. Assess the impact of factors such as aircraft type and age, engine type and age, ground conditions and operations, and cleaning procedures on bleed/cabin air quality. Examine measured contaminant levels in relation to existing guidelines and standards, and appropriateness of such guidelines to the cabin environment.

3. Examine relationships of perceptions and symptoms reported through questionnaires to contaminant concentrations and other objective measurements of the cabin environment, as well as occupant characteristics such as age and health status. Examine relationships of work related factors of flight attendants including duty schedules, work variability, sleep quality, effect of working multiple flights and flights crossing multiple time zones and other influencing factors. Consider separate subgroups such as passengers versus flight attendants, or subsets of either group with differing risks or sensitivities, in examining these relationships.

4. Provide conclusions in terms of pinpointing problems and their potential sources based on the understanding gained from this research project and in light of the prior research.

The final report shall describe in detail the methods used, shall summarize the data collected, and shall convey the results of the above analysis areas. The overall results of the research project should be presented in a clear and comprehensive document which: 1) discusses in detail the possible effects of cabin air constituents and other environmental and work related factors on health and comfort and, to the extent possible, the combined effects, taking into account real-life exposure levels; 2) distinguishes factors present in cabin air from factors present in aircraft but not related to air quality; 3) identifies possible factors encountered by occupants during flight and distinguishes them from factors encountered prior to flight; 4) identifies measured contaminants during flight versus ground operation; and 5) includes an evaluation of the measured contaminants, identifies human sensitivities (medical and olfactory). The final report must include a copy of the protocol and the status of its standardization.

The final report must provide recommendations for areas of future research and/or investigations. If the research results indicate that additional data gathering should be conducted, recommendations on the future study's test protocol must be given. The final report will be submitted for review to the PMC, which will include a representative from Aerospace Medical Association's (AsMA) Air Transport Medicine committee.

DELIVERABLES

a. For Part 1, the contractor will submit to the PMC for their review and approval an overall design within two months from the initiation of the Part 1 efforts. A report detailing the literature review and the protocol describing plans, procedures and test equipment will be submitted to the PMC four months into the project for review and approval. The Project Monitoring Committee must receive copies of all correspondence dealing with this project. For Part 2, detailed plans for collection of data including flight selection and quality assurance shall be submitted two months into the Part 2 project for review and approval.

b. Progress and Financial Reports in quadruplicate shall be made to the Society through its Manager of Research (MOR) at quarterly intervals; specifically on or before each January 1, April 1, June 10 and October 1 of the contract period. A copy of each progress report shall also be given to the TC 9.3 Aviation Research subcommittee at the same time it is given to the MOR.

c. A Final Report for each Part shall be prepared and submitted to the Society by the end of the contract period covering complete details of all research carried out on the project. Unless otherwise specified, six draft copies of the final report shall be furnished for review by the Project Monitoring Committee.

Following approval by the Project Monitoring Committee and the TC, final copies of the final reports will be furnished as follows:

- Four bound copies;
- One unbound copy, printed on one side only, suitable for reproduction;
- Two copies on CD(s); one in ASCII format and one in the word processing format used to produce the report.
- Collected data.

In addition, paper and electronic copies of the final reports along with a complete data set of all data collected (including questionnaire data) must also be submitted to organizations, which have contributed funds for this research. A list of such organizations will be available from ASHRAE Manager of Research.

d. One or more Technical Paper(s) shall be prepared in a form suitable for presentation at a technical review meeting. Upon approval by the technical committee, the presentation shall be made ready for a Society meeting. The Paper(s)

shall conform to the Society's "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publications Section.

e. A Technical Article suitable for publication in the ASHRAE JOURNAL, may be requested by the Society. This is considered a voluntary submission and not a deliverable.

LEVEL OF EFFORT

ASHRAE invites technical and cost proposals for Part 1. *Note that this solicitation is for Part 1 only*. Upon completion of the Part 1 effort, ASHRAE anticipates inviting proposals for Part 2 from the Part 1 contractor as well as two other organizations whose proposals for Part 1 were ranked high. The request for proposal for Part 2 is contingent upon availability of research funds and approval of ASHRAE Board of Directors.

The level of effort for Part 1 is anticipated to be at least 1.25 person-years, with the total project completed within 9 months of the initiation of work. The maximum funds allocated for Part 1 efforts are $175,000. The funding for Part 2 is anticipated to be in excess of $400,000.

EVALUATION CRITERIA TO BE USED BY THE PMC

In evaluating a proposal, the Project Monitoring Committee will first determine whether the stipulations for an acceptable proposal that are listed in the above statement of work have been met. In comparing proposals in which they are met, the committee will evaluate each proposal with respect to the following:

1) The proposer's approach and study design in meeting the project objectives. How the study builds on previous work and how it considers and address the risk of not meeting subobjectives.
2) ~~The relevance, length, and breadth of staff experience,~~ Demonstrated experience in areas of monitoring of air quality, ~~study design~~ design of experiments, statistical and related analysis of data including health outcomes. Required backgrounds include air quality monitoring, biostatistics, environmental epidemiology, instrumentation and measurement methods, health and medical sciences, standardization, and toxicology.
3) Demonstration of an understanding of the types of exposure and outcome (symptom) relationships to be assessed and provide justification for the types and numbers of flights necessary to satisfy the study objectives.
4) Ability to provide clear, comprehensive, scientifically defensible, and timely reports and publication of journal articles.

APPENDIX – A PARTIAL LIST OF RELEVANT REFERENCES

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19.20. CSS, "Airline Cabin Air Quality Study," Prepared by Consolidated Safety Services for the Air Transport Association of America, Washington, DC. 1994.
20.21. Dechow, M., "Measurement Results of Selected Contaminants within Cabin Air of Airbus Aircraft," Predevelopment Air Systems, Daimler-Benz Aerospace Airbus GmbH, Hamburg, Germany, 1996.
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